Theoretical Calculations of the Seasonal and Solar Activity Variations for Ionospheric Collision Frequency and Debye Length over Baghdad City

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ABSTRACT

In this study, two important ionospheric factors have been calculated, the collision frequency of electron and Deby length for a height range from 80 Km to a height approaching the maximum height of the F2 region of the ionosphere above the Earth's surface. Both above factors have been calculated for two different levels of solar activity and for two seasons (winter and summer). Also, six months were adopted for every level of solar activity and season. The estimation of collision frequency of electron is depends on the contribution of neutral constituents and ions. Three neutral atmospheric gases have been adopted to calculate the collision frequency, Molecular and atomic oxygen O_2 and O respectively and molecular nitrogen N_2, as well as the singly charged ions were taken into account in calculation.

الخلاصة

في هذه الدراسة تم حساب عنصرين اساسيين لدراسة الايونوسفير وهما كل من تردد التصادم وطول ديباي لنطاق ارتفاع يبدأ من ارتفاع **80 Km** الى ارتفاع مقارب لارتفاع قمة الطبقة **F2** فوق سطح الارض. تم احتساب هذين العاملين لمستويين مختلفين من النشاط الشمسي ولفصلين مختلفين. تم اعتماد ستة اشهر لكل مستوى نشاط شمسي، ثلاثة لكل فصل. ان حساب تردد التصادم للالكترون يعتمد على مساهمة العناصر المتعادلة و الايونات حيث تم اعتماد ثلاث عناصر غازيه وهي كل من الاوكسجين الجزيئي و الذري $\mathbf{O_2}$ و **O** على التوالي و النتروجين الجزيئي $\mathbf{N_2}$. بالاضافة الى الايونات ذو الشحنه المنفرده.

INTRODUCTION

The determination of plasma parameters, such as electron density and electron neutral collision frequency, is important for ionospheric plasma characterization. Any material is characterized by parameters that define the state and properties of the matter. For ordinary materials the most general set of parameters, are the density, pressure, and temperature. Plasma is defined as a quasi-neutral collection of charged particles which exhibits collective behavior.

Certain fundamental plasma parameters that are relevant to the work in this study are the ambient electron density or the angular plasma frequency w_{pe}, the electron-neutral and electron-ion collision frequency ν_{en} and ν_{ei} respectively.

Multiple methods and instruments have been developed over the years to measure these parameters. One of the popular instruments that is used to measure the electron density in plasma environments is the plasma impedance probe (PIP). Impedance probes have been used to measure the electron densities in the ionosphere as well as in laboratory conditions [1].

Collisions of free electrons with neutrals, ions or other electrons are important for various macroscopic phenomena. In the ionospheric E-region they determine the thermal and electrical conductivity of the plasma and thus the current systems which give rise to geomagnetic variations. Electron collisions also play an important role in the attenuation of radio waves propagating through the D-region [2].

The interaction in plasmas is very important phenomena. The simplest kind of interaction between single particles is a direct collision. This is not yet a collective plasma effect, since it involves interactions between individual particles and not between large groups of particles in the plasma or the plasma as a whole, but under the presence of collisions the particles already behave quite differently from what would be expected when using the single particle picture.

There are two types of plasmas, collisional and collisionless. In this study we concern with the former type. Collisional plasma divided into two classes, partially ionized plasmas and fully ionized plasmas. Partially ionized plasmas contains a large amount of residual neutral atoms or molecules while fully ionized plasma consists of electrons and ions only. In partially ionized gases direct collisions between the charges carriers and neutral dominates, while in the fully ionized plasmas direct collisions are replaced by coulomb collisions [3].

According to the previous section, this study has been divided into two parts, first the collisions between the electrons and the neutral constituents, and the interaction of electrons with the charged particle (i.e., ions). These collisions have been calculated using theoretical models for both types.

Calculation of the effective collision frequency and Debye length

1. Collision of electrons with neutral particles

These collisions differ fundamentally from collisions between charged particles because now the interaction forces are short-range (unlike the long-range coulomb interactions) and so the neutral can be considered simply as a hard body with cross section of the order of its actual geometrical size.

When a particle hits a neutral it can simply scatter with no change in the internal energy of the neutral, this is called elastics scattering. It can also transfer energy to the structure of the neutral and so cause an internal energy change in the neutral, this is called inelastic scattering. Inelastic scattering include ionization and excitation of atomic level transitions (with accompanying optical radiation) [4].

The collision frequency is inversely proportional to the mean free path, also depends on the speed of the particles. From the dependence of the mean free path on the density and on the cross section for collision, the collision frequency is related to the quantities by the following formula:

Collision frequency=Density * cross section * mean speed

$$\langle \nu \rangle = N_n \, \sigma \, \langle V \rangle \qquad (1)$$

Where N_n is the neutral particle concentration, σ is the cross section of the neutral particles and $\langle V \rangle$ is the mean speed of the electron [5]. According to Equation 1, three parameters must be calculated. Firstly, the cross section for collision between electrons and neutral particles, secondly, the mean speed of the electrons, finally, the concentration of the neutral particles.

Three effective neutral atomic and molecular constituents in the ionosphere (atomic and molecular oxygen, O and O_2 respectively and molecular nitrogen N_2) are taken into account for calculating the cross section of electron-neutral particles collision.

Nitrogen molecules are the most abundant of the earth's atmosphere. Electron collisions with nitrogen molecules play a fundamental role, for example, in the ionospheric and auroral phenomena in the upper atmosphere of the earth. They are also important processes in electrical discharges involving atmospheric gases. Those discharges constitute basic techniques in the field of gaseous electronics and plasma processing [6].

Oxygen molecules O_2 are one of the major components of the earth's atmosphere. Oxygen is an essential ingredient in various gaseous discharge processes like ozone formation. Atomic oxygen O is important in the upper atmosphere of the earth, since it is the most abundant species at the heights between 200 and 600 km [7, 8].

The physical cross section of the neutral particles (O, O_2 and N_2) can be simply calculated from the following formula [3]:

$$\sigma = \pi * r_n^2 \qquad (2)$$

Where r_n is the effective radius of the neutral particle. Table 1 summarizes the radii of the atmospheric constituents and the physical cross section [9].

Table 1: the radii & physical cross section of N2, O2 and O [10].

Species	N_2	O_2	O
Radius 10^{-10} m	1.3	1.2	0.6
Cross section 10^{-20} m^2	5.3	4.52	1.13

The second important parameter to calculate the collision frequency is the mean speed of the colliding particle (electron) which is estimated according to the Maxwellian distribution.

$$\langle v \rangle = \sqrt{\frac{8 k_B T_e}{\pi m_e}} \qquad (3)$$

Where kB =1.3806*10-23 J/Ko is the Boltzmann constant, me =9.1*10-31 kg is the electronic mass and Te is the temperature of the electron in ko [10].

The third term in Equation 1 specifies the concentration of the neutral constituents (N_2, O_2 and O). These concentrations have been calculated using the MSIS E-90 international model http://modelweb.gsfs.nasa.gov/models/msis.html. The MSIS E-90 international model describes the neutral temperature and densities in the earth's atmosphere from ground to thermospheric heights [11].

2. The Collisions of Electrons with Ions and Debye length

The second part of the effective collision frequency ν_{ei} is called the coulomb collision between electrons and ions in the ionosphere. The characteristics and effects of coulomb collision between charged particles in ionospheric plasma are very different from those of the more commonly collisions of neutral particles. As an electron moves through ionosphere, it simultaneously experiences the weak coloumb electric field forces surrounding the nearby charged particles, and it's direction of motion is deflected as it passes by each of them.

The coulomb potential and hence the electric field around any particular background charged particle in ionosphere is collectively shielded out at a distances beyond a Debye length. Thus the only background particles that exert significant forces on the test particles motion are those within about a Debye length of its trajectory. The coulomb electric field forces produced by individual background particles are small and can be assumed to be experienced randomly by the test particles as it passes close to individual background particles. The effect of many successive, elastic coulomb collisions of a test particle with background charged particles lead to a random walk (i.e., Brownian motion) process [12].

The coulomb collision frequency has the same functional dependence as Equation 1. The problem lies in determining the coulomb collisional cross section σ_c

and introduce the new parameter, the ion density n_i [13]. The coloumb collision frequency between electrons and ions of charge (Ze) is given by [10]:

$$\nu_{ei} = \frac{Z_i^2 n_i\, e^4}{2\pi\epsilon_o^2\, m_e^{\frac{1}{2}}\, \sqrt[3]{k_B\, T_e}} \ln(\Lambda) \tag{4}$$

where

$$\ln(\Lambda) = \ln(4\pi n {\lambda_D}^3) \tag{5}$$

is known as the coloumb logarithm, and λ_D is the Debye shielding length and defined by the following formula [13]:

$$\lambda_D = \sqrt{\frac{\epsilon_o K_B}{N_e e^2} T_e} \tag{6}$$

where ϵ_o=8.85*10^{-12} $\frac{F}{m}$ is the permittivity of free space and e=1.602*10^{-19} C is the electron's charge. We can simplify the previous equations by substituting the values of constants. The equation (7) becomes:

$$\lambda_D(m) = 69\sqrt{\frac{T_e(K^o)}{N_e(m^{-3})}} \tag{7}$$

and the logarithm scale is given by:

$$\ln(\Lambda) = 15.23 - 0.5\ \ln(N_e) + 1.5\ \ln(T_e) \tag{8}$$

So, equation of electron-ion collision frequency can be reduced to

$$\nu_{ei}(Hz) = 2.73 * 10^{-5}\,\frac{Z_i^2 n_i(m^{-3})}{\sqrt[3]{T_e\,(K^o)}} \ln(\Lambda) \tag{9}$$

Keeping quasi-neutrality [14]:

$$\Delta n_e = Z_i n_i \tag{10}$$

in mind, and for singly charged ions (Z=1), equation (10) becomes

$$\nu_{ei}(Hz) = 2.73 * 10^{-5}\,\frac{n_e(m^{-3})}{\sqrt[3]{T_e\,(K^o)}} \ln(\Lambda) \tag{11}$$

DATA USED FOR CALCULATION

In this study, the effective collision frequency of electrons with neutral particles and ions has been calculated. The presented study depends on three important atmospheric and ionospheric parameters, those are the neutral particle densities (N_2, O_2 and O). These densities have been obtained from the MSIS E-90 international model. Also, the electron density and electron temperature have been calculated using the IRI-2012 model http://iri.gsfc.nasa.gov.

This study has been implemented for two seasons, each one represented by three months December 2001, January 2002 and February 2002 for winter, while for summer, June 2002, July 2002 and August 2002 were adopted. Two different solar activities were adopted each season, low and high solar activity. The monthly sunspot numbers used in this study were calculated from the IPS (Radio and space services) http://www.ips.gov.au. These values were obtained for the solar cycle (23). Table (1) shows the values of the sunspot number with the corresponding date, and for local noon time (12 hr) of Baghdad city (33.35° N, 44.38° E).

Table (2) Observed Monthly Sunspot Numbers (IPS)

Season	Month	High Solar Activity		Low Solar Activity	
		Year	SSN	Year	SSN
Winter	December	2001	95.6	2007	16.9
	January	2002	114.1	2008	3.4
	February	2002	107.4	2008	2.1
Summer	June	2002	88.3	2008	3.1
	July	2002	99.6	2008	0.5
	August	2002	116.4	2008	1.1

MATERIALS AND METHODS

As mentioned above, the effective collision frequency has been calculated using the contribution of two different frequencies. Firstly, the electron-neutral particle collision frequency is calculated using equations (1, 2 and 3) as shown below:

$$< \nu_{e-n} >= N_n \sigma_n < v_e >$$

Substituting the value of the constants in the equation of both the cross section and the mean speed of the electron, we have

$$< \nu_{e-n} >= 6215.6\ N_n \sigma_n \sqrt{T_e}\quad (Hz) \tag{12}$$

So, the total electron-neutral collision frequency ν_{te-n} is given by the following summation:

$$\nu_{t\,e-n} = \sum_{\text{neutral species}} < \nu_{e-\text{neutral species}} > \tag{13}$$

Also, the second part which defines the collision frequency between electron and ion is calculated using equations (9 and 12). These equations have been programmed and plotted using Matlab2013 version.

RESULS AND DISCUSSIONS

Figures (1-2) show the height variations of the electron collision frequency and Debye.

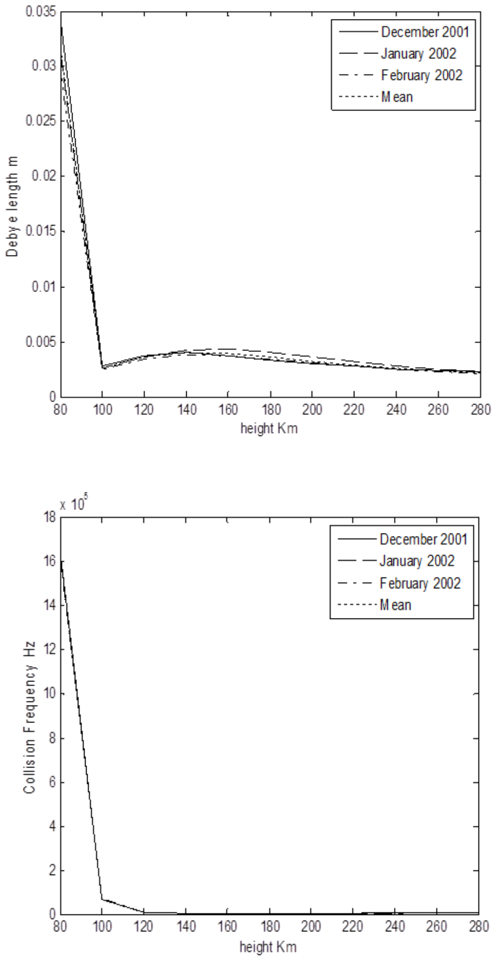
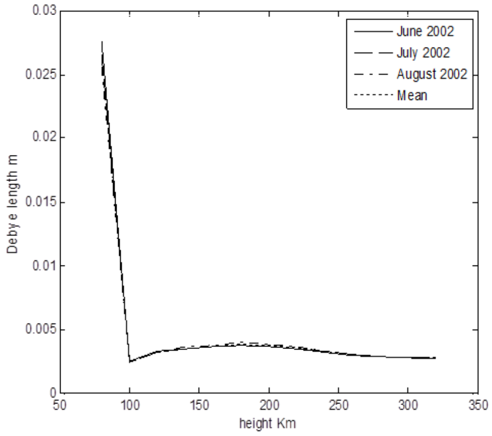


Figure (1): Debye length and effective collision frequency for Winter months with their means.



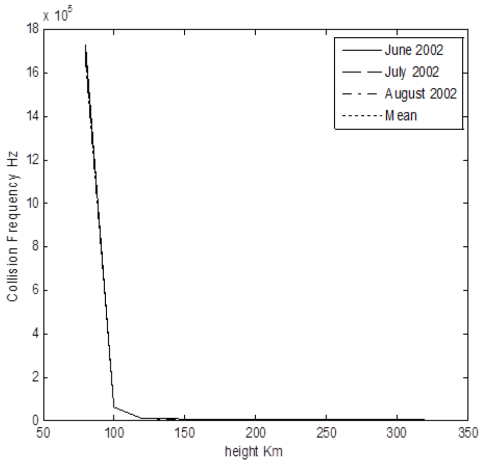


Figure (2): Debye length and effective collision frequency for Summer months with their means length.

These height variations are shown for two seasons each one represented by three months.

Figure (3) shows the mean values of Debye length and the effective collision frequency for both

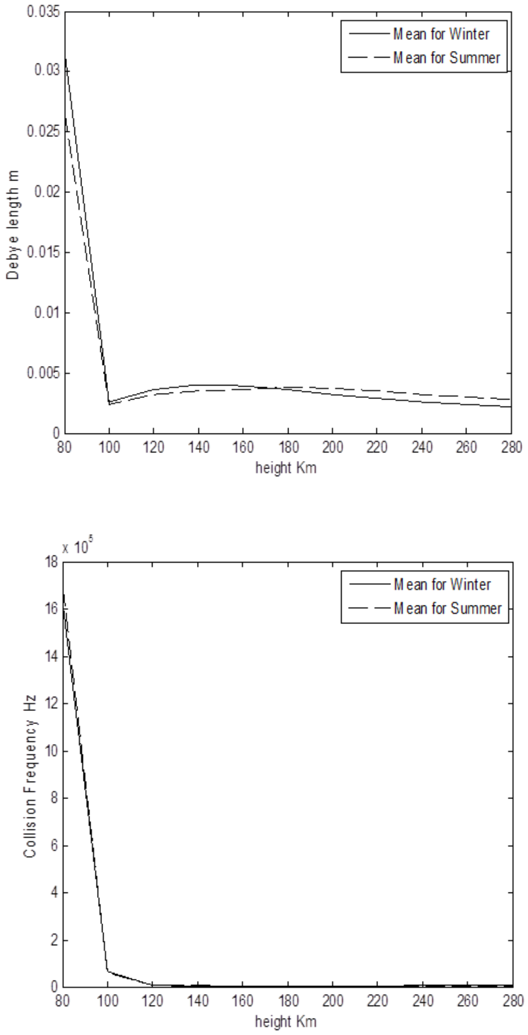


Figure (3): The mean values for Debye length and effective collision frequency for winter and summer months.

Winter and summer months. Also, the height variations of Debye length and effective collision frequency for two different solar activities with their means where every activity specified by three months with different monthly sunspot numbers (MSSN) have been shown through figures (4,5 and 6).

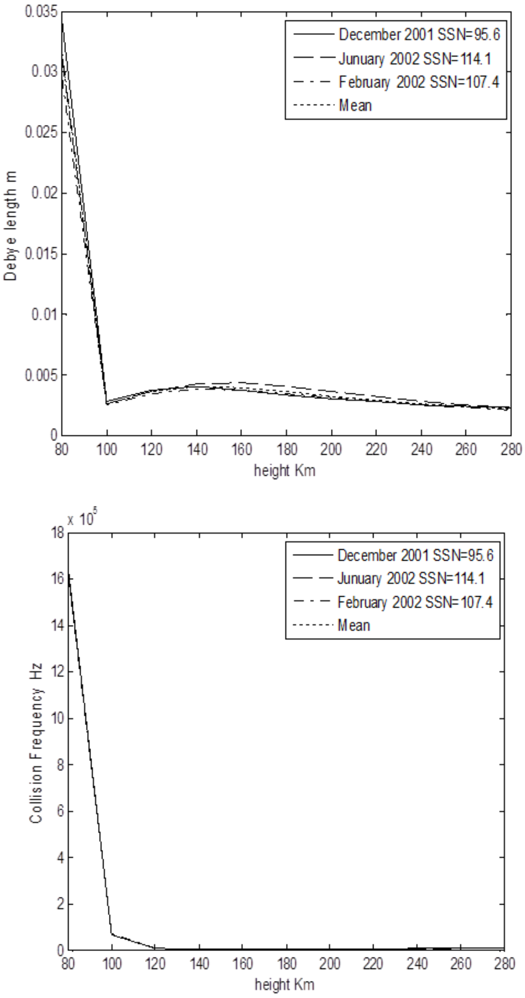


Figure (4): Debye length and effective collision frequency for different high solar activities.

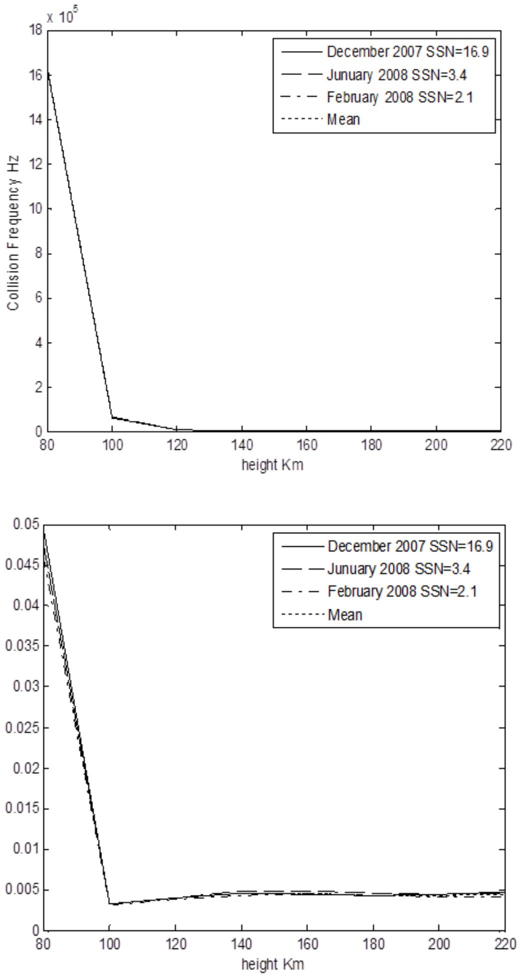
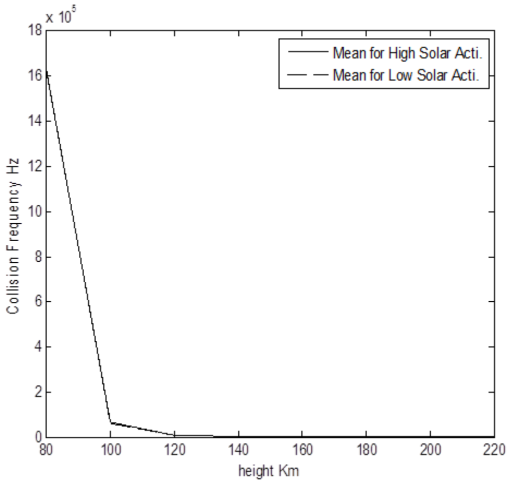


Figure (5): Debye length and effective collision frequency for different low solar activities.



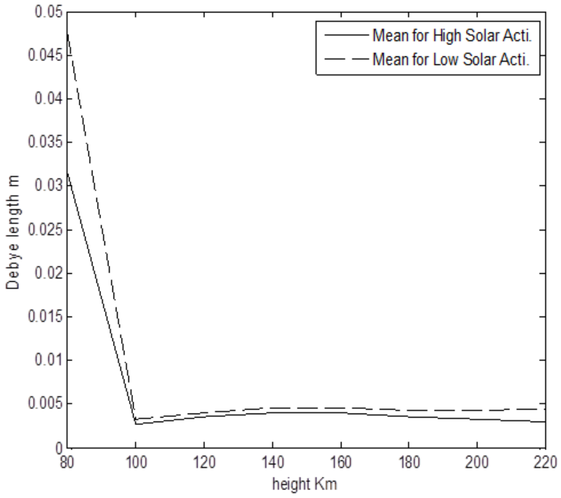


Figure (6): The mean values for Debye length and effective collision frequency for high and low solar activities.

1. Seasonal variation

Figures (1-2 &3) show Debye length and the effective collision frequency of the electron for six months, three months for each season (December, January and February for winter, June, July and August for summer), and the mean value for them respectively. From figure (3), firstly, it is seen that the mean of both Debye length and collision frequency decreases with height. Secondly, the mean Debye length for winter starts from (0.03157 m) to (0.00225 m) while for summer begins from (0.02655 m) to (0.002842 m), and the mean collision frequency starts from (0.067532 MHz) to (0.007293 MHz) for winter while for summer begins from (0.05999 MHz) decreasing to (0.0045648 MHz). Thirdly, both the mean values for two seasons have the same behavior and approximately the same values where the correlation coefficient for the mean of collision frequency between the two data sets of both seasons is (0.99701) and for the mean of Debye length is (0.998602) which indicates a high a positive correlation. Finally, in the low heights above the earth's surface (about 120-160 Km), the values for winter are greater than for summer while for height above 160 Km, summer has greater values.

2. Solar activity variations

Figures (4-5 & 6) show the height variation of Debye length and the collision frequency of the electron for two solar activities (high and low) and their means respectively, each activity has been represented by six months, three for winter and the same for summer. The mean Debye length have the same behavior for two levels of the solar activity, and the low solar activity has greater value than for high solar activity. The correlation coefficient of Debye length between two data sets for both levels is (0.999363). The mean value of the effective collision frequency shows an increment for high solar activity and the correlation coefficient is 0.99999. Deby length and the effective collision frequency for high solar activity have the range values (0.031572 m to 0.002938 m) and (1.618865 MHz to 0.004532 MHz) respectively, and for low solar activity their means begins from (0.04751 m to 0.0045252 m) and (1.62585 MHz to 0.001972 MHz) respectively.

CONCLUSIONS

From Figures (3 & 6), which present the mean values of the height variation of the mean of Debye length and the collision frequency of the electron as a function of season and solar activity, show the high positive correlation between two data sets for the variation with season and solar activity. Also, in the low heights above the earth's surface (about 120-160 Km), the values for winter are greater than for summer while for height above 160 Km, summer has greater values. Mean Debye length and the mean collision frequency have the same behavior for two levels of the solar activity. For low solar activity mean Debye length has greater value than for high solar activity. The mean value of the effective collision frequency shows an increment for high solar activity.

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